Energy and transverse momentum dependence of single-spin asymmetry of very forward neutron in polarized pp collision

Kiyoshi Tanida for the PHENIX collaboration

Department of Physics and Astronomy, Seoul National University, Seoul 151-742, Korea

E-mail: tanida@phya.snu.ac.kr

Abstract.

We measured energy ($\sqrt{s}$) and transverse momentum (p_T) dependence of single-spin asymmetry (A_N) of very forward neutron in transversely polarized proton collisions with $\sqrt{s}$ from 62 to 500 GeV. The observed asymmetry linearly increases with p_T up to $\simeq 0.3$ GeV/c. On the other hand, $\sqrt{s}$ dependence, which shows higher asymmetry for higher $\sqrt{s}$, can be interpreted as due to p_T dependence. A one-pion exchange model fails to reproduce the data. This suggests that the mechanism for forward neutron prodction is not understood yet, and that we need to consider more processes for forward neutron production.

1. Introduction

With first polarized proton collision at $\sqrt{s} = 200$ GeV at Relativistic Heavy Ion Collider (RHIC), a large single transverse spin asymmetry (A_N) for neutron productions in very forward kinematics was discovered [1]. The discovery shed new light on the production mechanism of such leading baryons in the region where purturbation is not applicable.

The cross sections for inclusive production of zero-degree neutrons for unpolarized pp collisions are measured at ISR from $\sqrt{s} = 7$ to 64 GeV [2, 3]. The x_F spectrum of the shows a peak around $x_F \sim 0.8$ and is found to have almost no $\sqrt{s}$ dependence. The preliminary cross-section at $\sqrt{s} = 200$ GeV we reported earlier [4] is consistent with the ISR result. These features are reasonably explained by one pion exchange (OPE) models, in which the incoming proton emits a pion which scatters on the other proton [5, 6].

In this article, we report the $\sqrt{s}$ and p_T dependence of A_N for very forward neutron in transversely polarized proton collisions with $\sqrt{s}$ from 62 to 500 GeV. It is interesting to see if the OPE mechanism can explain A_N as well, especially its transverse momentum (p_T) dependence, because A_N gives information to separate spin-flip and spin-non-flip amplitudes.

2. Experimental Setup

A plan view of the experimental setup for very forward neutron measurement at PHENIX is shown in Figure 1. Neutrons have been measured by Zero-Degree Calorimeter (ZDC) with a position-sensitive Shower-Max Detector (SMD) [7]. ZDC is composed of cupper-tungsten alloy absorbers with optical fibers and each module has 1.7 interaction length (λ_I). A photomultiplier collects Cherenkov lights via the optical fibers in each module. Three ZDCs are located in

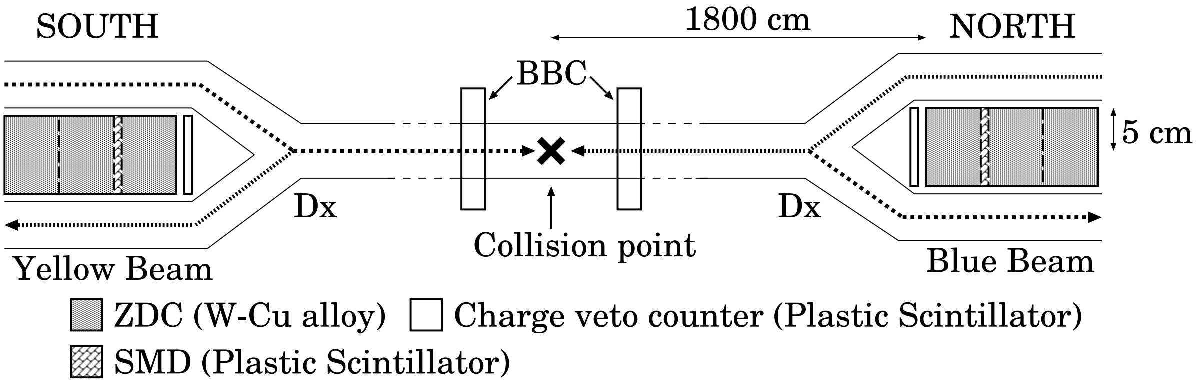


Figure 1. A plan view of the experimental setup at PHENIX (not to scale). Principle components for the leading neutron measurement are shown.

series (5.1 λ_I in total) at $\pm$1800 cm away from the collision point within the small acceptance, covering 10 cm in the trasverse plane. SMD consists of x-y scintillator strip hodoscopes and is inserted between the first and second ZDC modules at the position of maximum hadronic shower approximately. The x-coordinate (horizontal) is sampled by 7 scintillator strips of 15 mm width, while the y-coordinate (vertical) is sampled by 8 strips of 20 mm width, tilted by 45 degrees. These detectors are located down stream of the RHIC-DX magnet so that charged particles from collisions are expected to be bent away. A forward scintillation counter, covering 10×12 cm, has been installed in front of the ZDC to remove charged particle backgrounds.

The data was collected by two sets of triggers for the neutron measurement. One is the ZDC trigger for neutron inclusive measurements by requring energy deposit in either side of the ZDC (the north side or the south side) above 5 GeV. The other is a coincidence trigger of the ZDC trigger with hits in Beam Beam Counter (BBC), which consists of 64 sets of quartz Cherenkov counters covering $\pm$(3.0–3.9) in pseudorapidity and 2π in azimuthal angle.

An absolute scale for the energy measurement is determined by the 100 GeV single neutron peak from peripheral heavy ion collisions. The response of the detectors was studied by Geant3 with GHEISHA, which well reproduced the response of the prototype ZDC. The energy resolution obtained from the simulation can be described by $\Delta E/E = 65/\sqrt{E\ (\mathrm{GeV})} + 15$ (%), which is consistent with the observed width of one neutron peak at 100 GeV.

Neutron position is reconstructed by the energy deposit in SMD scintillators with the centeroid method. The position resolutions were estimated by the simulation to be around 1 cm for the neutron energy at 100 GeV. The reliability of the position measurement was checked by comparing hadron shower shapes of the real and simulation data. Then, based on the obtained position and neutron energy (E_n), p_T was calculated as $p_T = E_n \sin\theta_n \sim E_n r/d$, where θ_n is the reaction angle, r is the distance from the beam center to the hit position at ZDC, and $d = 1800$ cm is the distance from the collision point to the ZDC. The single-spin asymmetry, A_N, was calculated using the square-root-formula. Smearing due to finite position resolution and finite acceptance is corrected for using simulations.

3. Results and Discussions

The obtained A_N for forward neutrons are plotted in Figure 2, as functions of reaction angle. Significant neutron energy (x_F) dependence was not observed [4]. A_N for backward neutrons are all consistent with zero.

The observed $\sqrt{s}$ dependence could be interpreted as p_T dependence, as shown in Figure 3, which shows a linear increase of A_N with respect to p_T. As p_T is proportional to $\sqrt{s}$ for the

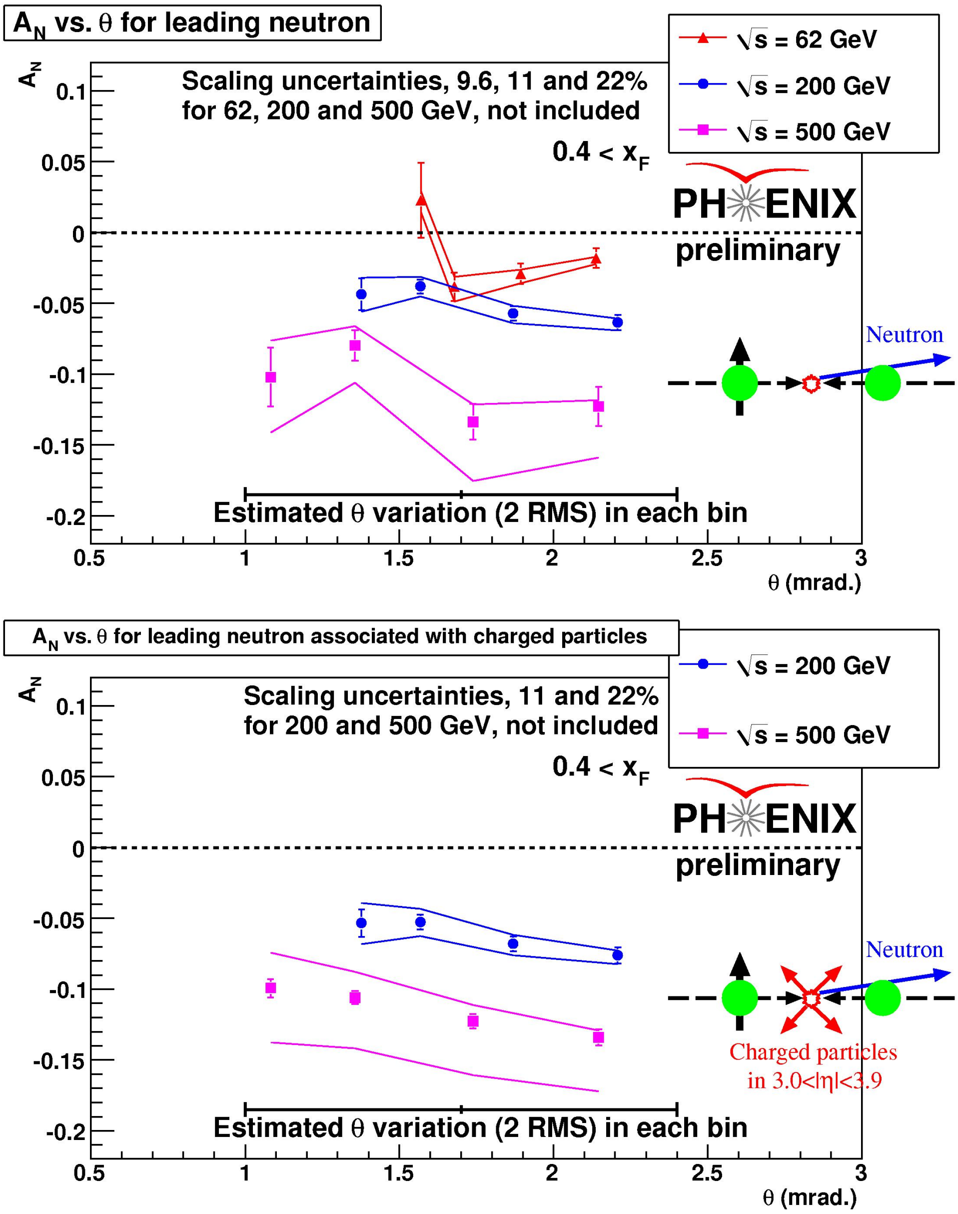
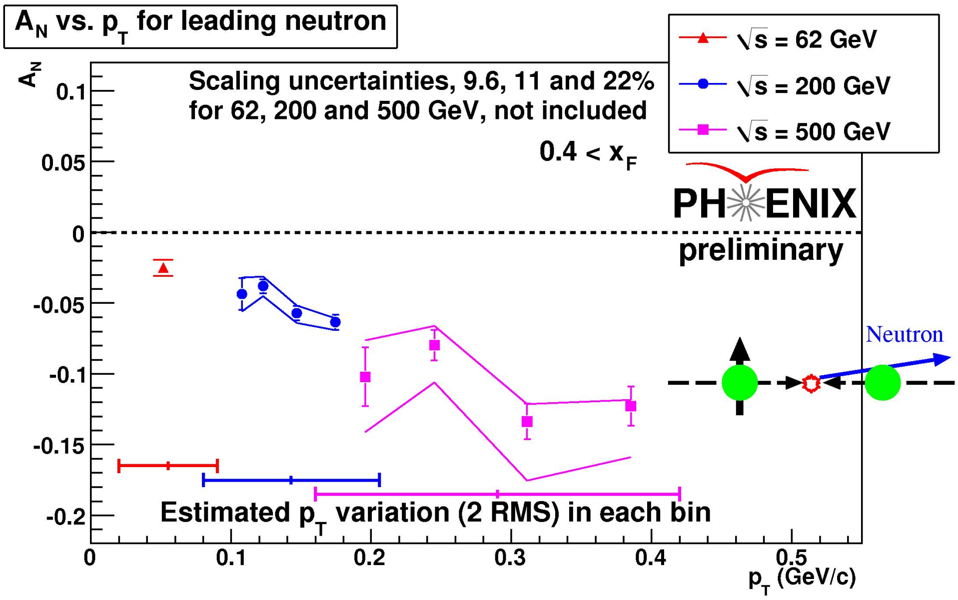


Figure 2. The measured asymmetries for forward neutrons as functions of reaction angle. Top: for inclusive neutrons (ZDC single trigger). Bottom: for neutrons with associated particles (ZDC-BBC coincidence trigger). Neutrons with $x_F > 0.4$ are selected. For the horizontal axis, the plotted positions give the average angles and their variation is also plotted as horizontal bars.

same θ_n and x_F, the asymmetry could be larger for higher $\sqrt{s}$ even if there would be no actual $\sqrt{s}$ dependence.

On the theory side, Kopeliovich *et al.* give their calculation for $\sqrt{s} = 200$ GeV based on a OPE model [8]. They obtained small asymmetries ($|A_N| < 0.01$) for $p_T < 0.2$ GeV/c which is the range of our measurement at $\sqrt{s} = 200$ GeV, and thus failed to reproduce our result. Note that their calculation is for the x_F range between 0.6 and 0.9 which is narrower than



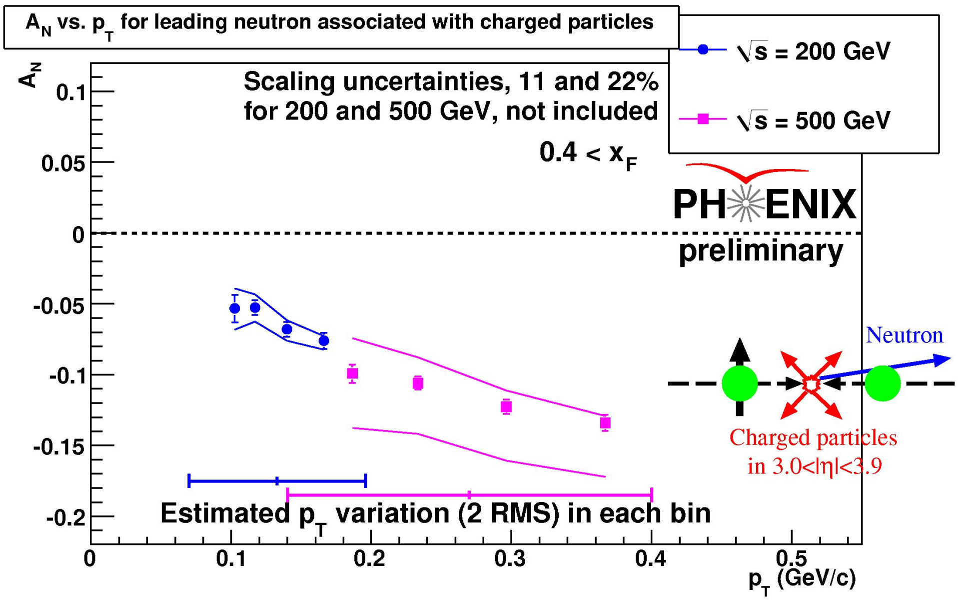


Figure 3. The measured asymmetries for forward neutrons as functions of p_T. Top: for inclusive neutrons (ZDC single trigger). Bottom: for neutrons with associated particles (ZDC-BBC coincidence trigger). Neutrons with $x_F > 0.4$ are selected. For the horizontal axis, the plotted positions give the average p_T and its variation is also plotted as horizontal bars.

our measurement ($x_F > 0.4$), but the this difference would not have significant effect since x_F dependence was found to be small in our measurement [4]. Within their model, the smallness at low p_T is rather natural because both of the spin-flip amplitude and the relative phase vanish for $p_T \to 0$. Therefore, they argued that one should include other mechanisms beyond OPE, for instance, interference of pion and a_1 exchanges.

4. Summary

Single spin asymmetry for very forward neutron production in pp collision is measured for $\sqrt{s}$ = 62, 200, and 500 GeV. A significant $\sqrt{s}$ and p_T dependence was observed, while no x_F dependence was seen. The $\sqrt{s}$ can be interpreted as due to p_T dependence. A model calculation based on OPE mechanism failed to reproduce the results. Therefore, the mechanism for the observed large A_N is still a mystery.

[1] Bazilevsky A et al. 2007 *Phys. Lett.* B **650** 325

[2] Flauger W et al. 1976 *Nucl. Phys.* **B109** 347

[3] Engler J et al. *Nucl. Phys.* **B84** 70

[4] Togawa M on behalf of the PHENIX collaboration 2007 *Proc. Int. Spin Physics Symposium* (Kyoto: AIP Conference Proceedings) p 689

[5] Nikolaev N N, Schafer W, Szczurek A and Speth J 1999 *Phys. Rev.* D **60** 014004

[6] DfAlesio U and Pirner H J *Eur. Phys. J.* A **7** 109

[7] Adler C et al. 2001 *Nucl. Instr. Meth.* A **470** 488

[8] Kopeliovich B Z, Potashnikova I K, Schmidt I and Soffer J 2008 Leading neutrons from polarized pp collisions *Preprint* hep-ph/0807.1449